SAM analysis in frontal lobe epilepsy for the surgical strategy

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1. Introduction

When surgical treatment against intractable frontal lobe epilepsy (FLE) is considered, epileptogenic zone is not easy to delineate by scalp EEG. Epileptogenic zone often does not involve wide cortex, but the epileptic discharge also propagates rapidly. So, prolonged electrocorticography (ECoG) has been recommended, especially in nonlesional cases.

The intractable seizure at the onset of the early childhood often associates with organic brain damage, and brings down mental retardation at worst. So, the invasive monitoring is often difficult to apply to such retardant children without cooperation. Therefore, multimodal noninvasive examinations are required in such cases.

To date, synthetic aperture magnetometry (SAM), one of the spatial filtering techniques of MEG, is ready to use and we have once introduced the SAM analysis of MEG [1, 2]. In this paper, we report the clinical application of this analysis, as the alternative to invasive study, for determining surgical strategy in a boy with intractable FLE.

2. Patient

Case report

A 9-month-old boy was referred to the pediatrician, because his parent noted his physical retardation of his left side and the development of the complex partial seizure (CPS). The CPS showed the still posture and the gaze in a few seconds of the ictus. Although the medication of anticonvulsants started since the age of 1 year on the grounds that EEG showed the interictal spikes of high amplitude on the right frontal region, the CPS developed refractory and led to being affected by numbers of intractable seizure in a day. CPS deteriorated and the type of CPS changed to the tonic posture of quadriceps with the loss of consciousness in a few minutes. He showed obviously the retardation of the development. He has no meaning word and no ability of left hand grasping at the age of five.

Multimodal examinations

Interictal spikes appeared most on the right frontal region. Ictal EEG showed bifrontal slow rhythm at first during the ictus and huge sharp wave afterward. CT and MRimage suggested no pathological abnormality. Positron emission tomography (PET) showed no hypometabolic area. Only interictal single photon emission computed tomography (SPECT) indicated the low perfusion of his right frontal lobe in imaging techniques.

3. Methods

MEG recording and magnetic source imaging (MSI)

A helmet-shaped 64-channel magnetometer was used for MEG data acquisition. 10 seconds of MEG data was collected by one manual trigger during the online visual analysis of the simultaneously recorded EEG. Total 200seconds of data was collected during 2hours of MEG examinations. Raw MEG data were filtered from 1.5 to 80Hz for the subsequent analysis. Then, the calculation of the single equivalent current dipole (ECD) sources were performed by the original software to best fit the measured magnetic fields. The estimated ECD sources were superimposed on the MRimage using the same fiducial markers with those of MEG data acquisition.

SAM virtual sensor analysis (SAM-VS analysis)

SAM is one of the filtering techniques, based on the non-linear constrained beamformer method. When SAM is applied to the analysis of MEG, SAM can estimate the change of the sequential current density of the arbitrary set region in the brain. (The detail of the algorithm is described elsewhere [1, 4].) The arrangement of such arbitrary regions in the brain is thought as the virtual sensors, which could measure the electrical activity in the brain as if subdural grid electrodes could do.

The MRimage was orthogonized on y-axis, which bound the both markers before the tragus, on x-axis, which bound the center of y-axis and the nasion, and on z-axis, which was rectangular to both x- and y-axis. Based on this orthogonized MRimage, the brain was divided spatially into the 252 voxels with the 1.5cm width of lattices (Fig. 1). Each voxel was considered as SAM-VS. SAM was applied to the raw data, and estimated SAM currentodensitogram of each virtual sensor.

Intraoperative electrocorticography (ECoG)

ECoG was measured from both frontal lobes

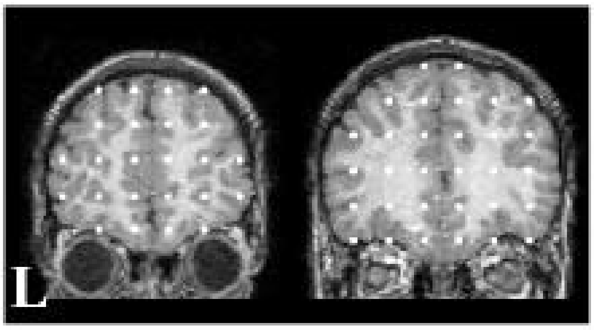

Fig. 1 *SAM virtual sensors. The distance of the neighboring sensors was 1.5cm. 64 of 252 sensors were used for the analysis.*

before the callosotomy under the general anesthesia of sevoflurane without nitrous oxide.

4. Results

MSI

68 epileptic discharges were disclosed in the MEG data. These epileptic discharges consisted not of a single spike, but of multiple spikes (Fig. 2). The peak phase of the spike had the subtle difference at each SQUID sensor. These spikes, if anything, revealed rarely same phase. 30 ECDs indicated the sources in the right frontal lobe and 1 did in the left. Dipoles were apt to localize into the deep white matter (Fig. 3). Average dipole moment indicated 390nA-m and the average error indicated 15%.

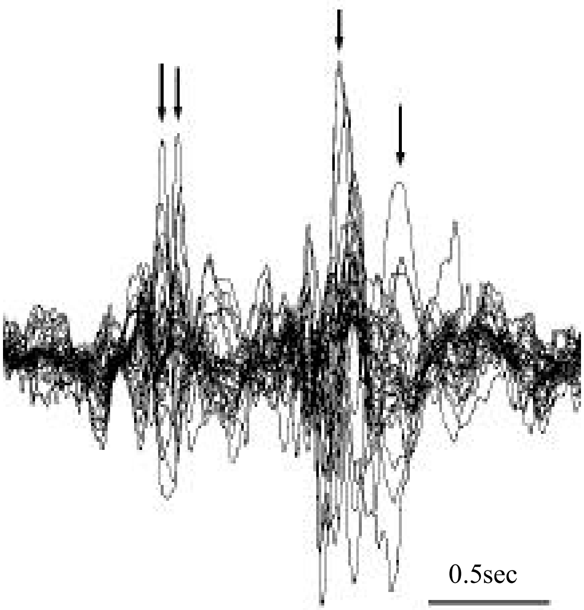

Fig. 2 *Epileptiforme discharge consisted of multiple spikes.*

SAM-VS analysis

SAM-VS analysis indicated that epileptic discharges originated from the right frontal region in

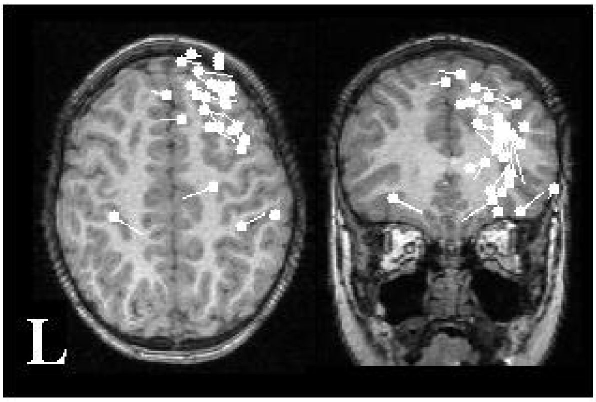

Fig. 3 *ECD analysis. 29 dipoles were estimated deep in the right frontal lobe.*

13 instances, the left frontal region in 2 instances, and the bifrontal region simultaneously in 26 instances. These discharges quickly spread over the ipsilateral and contralateral frontal lobes at times. However, right frontal SAM-VSs revealed larger electrical moments than the left SAM-VSs. 3 regions were disclosed as the epileptic area where the epileptic discharges originated initially and yielded the largest moment in the SAM-VS analysis; the right frontobasal region, the left frontobasal region, and the interhemispheric region (Fig. 4, 5). Three epileptic discharges were apt to propagate from the frontopolar area to the suprafrontal region along the cingulate gyrus.

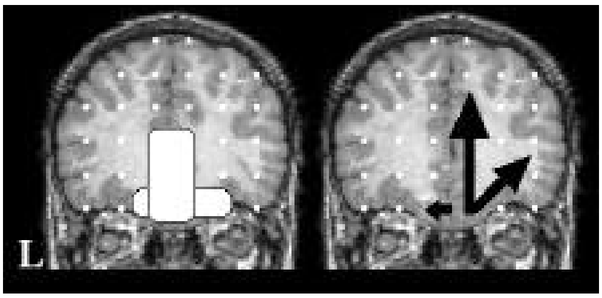

Fig. 4 *Three regions as the origins of epileptic dishrags.*

ECoG

Before the operation, the high voltages of epileptic discharges were simultaneously recorded on the bilateral frontal lobes, especially on the interhemispheric region (Fig. 6). After the callosotomy, most epileptic discharges appeared on the right frontal lobe, and a few spikes were observed on the left independent of the right epileptic discharges.

5. Discussion

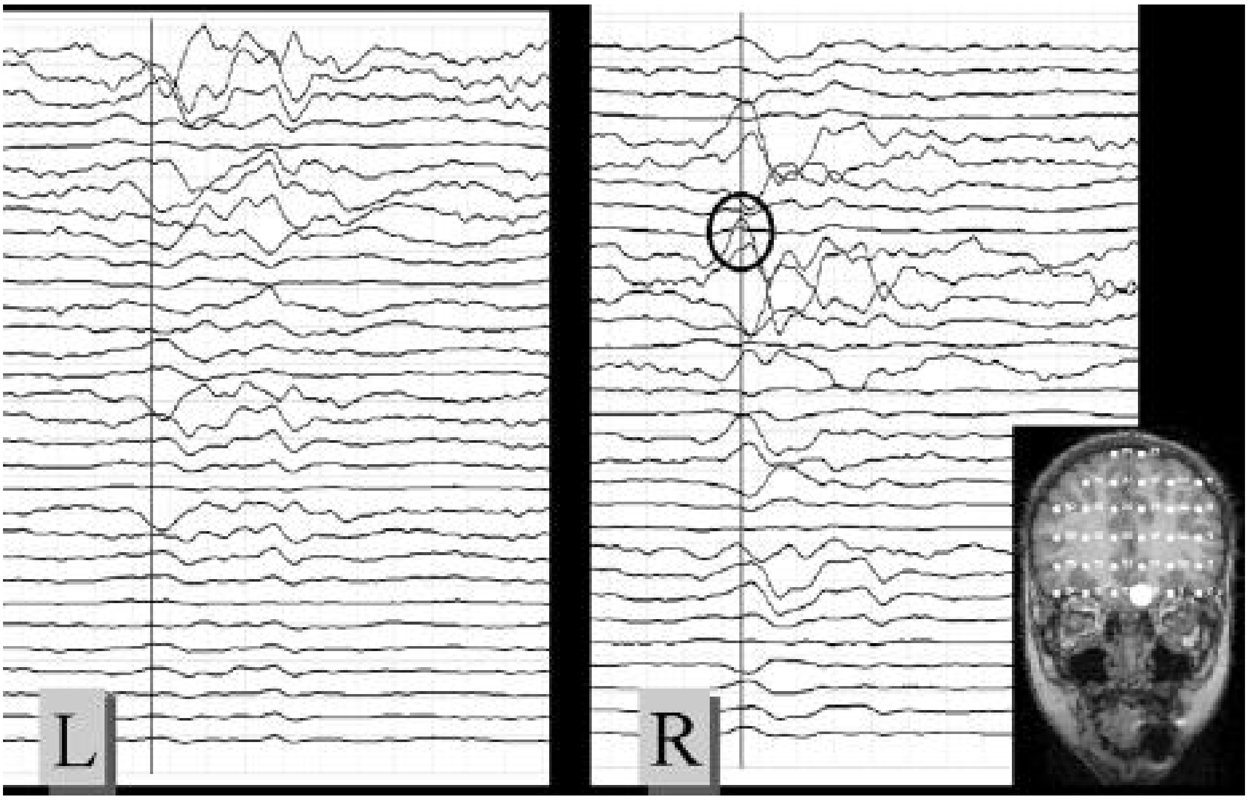

Fig. 5 SAM currentodensitogram. Epileptic discharge originated from the white-circled virtual sensor.

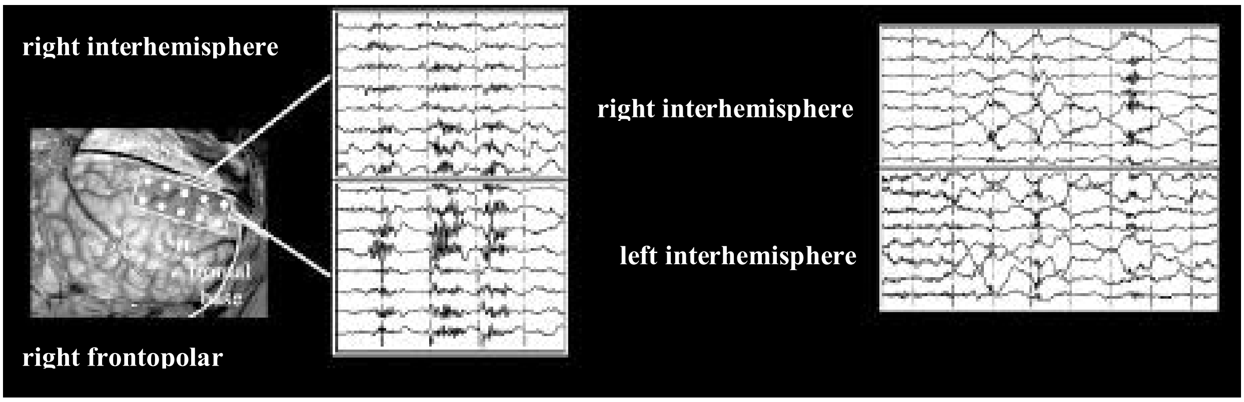

Fig. 6 Intraoperative ECoG. Bilateral epileptiforme synchrony was observed.

SAM overcomes solving the inverse problem of the magnetic field. This technique has already contributed to the analysis of theta rhythm and eventrelated desynchronization [3, 4]. SAM-VS analysis and SAM movie analysis were supposed to be the useful analytical method for the classification of temporal lobe epilepsy and the understanding of the electrical pathophysiology [2]. However, there was no reliable evidence of the SAM-VS analysis. In this paper, the bilateral epileptic activity detected by SAM-VSs in the interhemispheric region was confirmed by the intraoperative grid study indirectly.

The generalized epileptiforme discharges are called secondary bilateral synchrony (SBS) in FLE [8]. The pathogenesis of the SBS is not evident, and it is thought to be the fast spread of epileptic discharge from the focus to the contralateral region through the thalamus or through the corpus callosum. The SBS of our case was supposed to be derived from the focus of the right frontal lobe, because epileptic discharges were isolated into the right frontal lobe after the callosotomy. MEG showed most spikes did not have same peak phase of epileptiforme discharge, though scalp EEG showed such electrical phenomenon as the SBS attenuated by the skin the bone. Our results of SAM-VS analysis revealed the complex electrical activity that was consists of the rapid propagation to the contralateral side and the spread along the interhemispheric region. These findings suggested that the SAM-VS analysis was comparative to the ECoG study and that SAM-VS analysis might have represented such electrical phenomenon of SBS.

FLE is the second largest group of localization related epilepsy. But surgical out come results in unfavorable one [5 6]. Multimodal examinations are required for the surgery of FLE. Recent report mentioned predictive factors for the outcome of FLE surgery and only the absence of generalized EEG signs correlated independently with surgical outcome [7]. Another report noted that the earliest spike cluster correlated the seizure origin in 84% and the site of the highest spike frequency correlated in 53% of patient [9]. The analysis of the earliest magnetic field by SAM-VS was supposed to be useful to understand the epileptic region and to make surgical strategy.

6. Conclusion

Our results indicated the SAM-VS analysis could clearly demonstrate the origin of epileptic discharges and its sequence of spread with high spatial and temporal resolution, though the discharges showed no dipolar pattern of magnetic field. It was reasonably certain the results were comparable to the ECoG study. SAM-VS analysis worked as the alternative to the subdural electrodes noninvasively.

Acknowledgements

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